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FIELD STUDY OF THE AgPO_3 GLASS
PERSONNEL DOSIMETER
(U. S. NAVY DT-60)

by

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ABSTRACT

The U.S. Navy DT-60 dosimeter was evaluated under field type conditions as to its reproducibility and accuracy of gamma, X ray, thermal and fast neutron, and mixed radiation responses.

Gamma and X ray responses from 25 to 600 rads at energies in excess of 200 kev were found to be accurate within 20 per cent in 92 per cent of 160 dosimeters examined.

Because the DT-60 was found to have no detectable fast neutron response, effort was directed toward exaggerating the thermal neutron response to approximate the total neutron dose from a nuclear detonation and also toward eliminating any neutron response in a mixed neutron-gamma field. This was accomplished by various combinations of lithium, paraffin, and cadmium shielding.

Data indicate that the DT-60 dosimeter can be modified to approximate more closely doses from specific types of mixed radiations; however, this generally detracts from its value in approximating other types of mixed radiation doses.

A paired system of dosimeters, in conjunction with one of the fast neutron dosimetry systems mentioned within this report, is proposed as being the most satisfactory arrangement to approximate mixed radiation doses to personnel in the field.

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CHAPTER 1

INTRODUCTION

About 5 years ago the U.S. Air Force and Navy completed the issue of a silver-activated phosphate glass ionizing radiation personnel dosimeter to all of their military personnel. These dosimeters (DT-60) were designed under Navy contract and intended as lifetime accumulating or disaster type devices that could be read whenever and as frequently as required by use of a specially designed reader (CP-95). At least several of the CP-95 readers were available on each military installation to permit yearly records of accumulated dose to be made and included in the medical charts, preferably at the time of the yearly physical examination. Such an accumulating background dose could thus be used as a lifetime history of the amount of radiation acquired by the individual. Additionally, the yearly readings would provide a base line in estimating the extent of any acute exposure between yearly readings. The

Presidential decision to suspend U.S. testing of nuclear weapons and the Los Alamos Scientific Laboratory's interest in personnel dosimetry were equally responsible for the decision to conduct a series of experiments designed to evaluate the adequacy of the DT-60 in measuring mixed radiations from nuclear reactors and detonations.

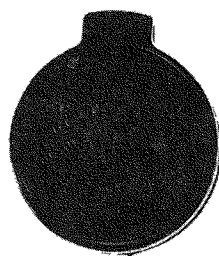
Early in the work, the realization of several inadequacies of the AgPO_3 system led to more elaborate field exposures conducted in Nevada during Phase II of the Hard-tack series. These field exposures were designed more toward possible means of improving the DT-60 than toward a further examination of its basic characteristics.

CHAPTER 2

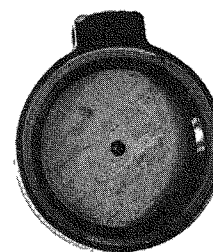
DESCRIPTION AND THEORY¹

The DT-60 dosimeter (AgPO_3 system) is shown in Fig. 1. It consists of a $3/4 \times 3/4 \times 3/16$ in. block of silver-activated phosphate glass sandwiched between two ~ 30 mil lead filters and encased in a circular plastic locket measuring $1-1/2 \times 1/2$ in. The entire device is about the size of a pocket watch and weighs approximately 1 ounce. The locket can be opened by applying a two-pronged wrench to the base to which the glass block is fixed. The base can be inserted for reading into the CP-95 fluorimeter (Figs. 2 and 3).

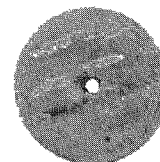
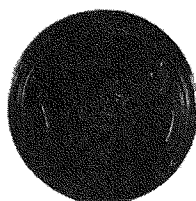
The fluorimeter consists of an ultraviolet source used in exciting the silver-activated phosphate glass and a phototube tied to a meter calibrated in roentgens that measures the intensity of the luminescence of the glass when so excited. Ultraviolet light in the 3600 A range is achieved by an RP-12 "black light" lamp fitted with a



ASSEMBLED



DISASSEMBLED FOR READING



DISASSEMBLY OF COMPONENTS

Fig. 1. DT-60 dosimeter assembled and disassembled.



Fig. 2. CP-95A reader.

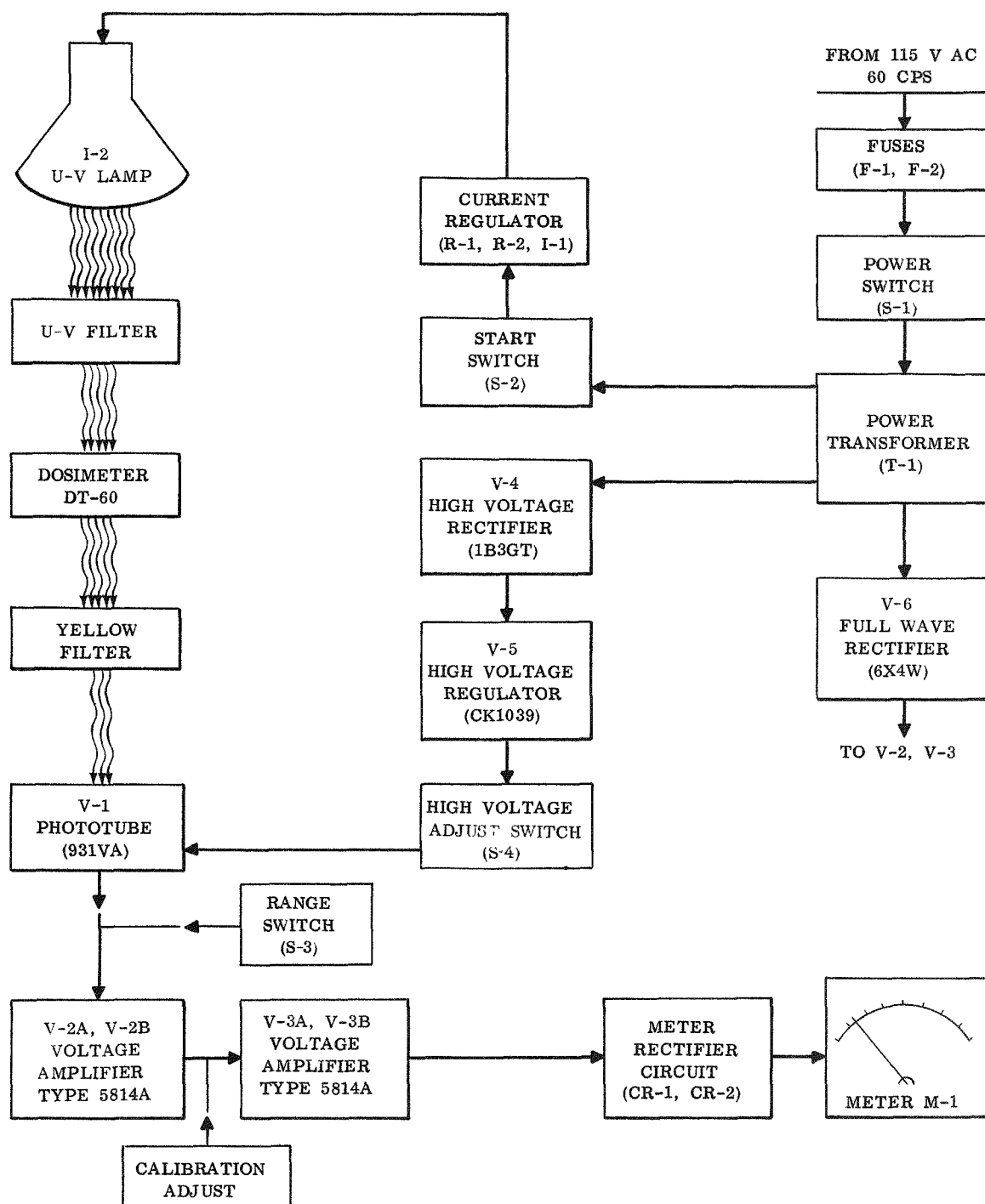


Fig. 3. CP-95A functional block diagram.

Corning 5860 filter. Fluorescence from the glass is filtered by a Corning 3482 yellow filter before impinging upon a 931VA photomultiplier. The meter has a 0 to 200 r and a 0 to 600 r scale. The reader measures 9 x 9 x 15 in., weighs approximately 30 pounds, and is operated on 115 volts dissipating ~40 watts.

The silver-activated phosphate glass used in the DT-60 is reported as having the following composition: 50 per cent $\text{Al}(\text{PO}_3)_3$; 25 per cent $\text{Ba}(\text{PO}_3)_2$; and 25 per cent KPO_3 , to which is added 8 per cent by weight AgPO_3 . Electrons liberated by exposure to ionizing radiation are captured by Ag^+ ions of the glass, which become reduced to "atomic" silver centers (Ag^0). Ultraviolet light in the 3600 Å region is absorbed by these Ag^0 centers, raising them to an excited state from which they return by emission of an orange fluorescence. The number of Ag^0 centers, and hence the intensity of orange fluorescence, is a function of the dose of ionizing radiation received. For this particular dosimeter, it appears to be proportional to the dose received (at least from 20 to 600 r, which are the practical limits of the CP-95A reader).

CHAPTER 3

CHARACTERISTICS

3.1 General

Outwardly, the assembled DT-60 appears to be quite rugged. However, an examination of 160 dosimeters revealed the following internal defects:

1. Poor seal between halves of locket. Missing or damaged gaskets were primarily responsible, but occasionally damaged threads were observed.

2. Glass element or one or more lead filters loose in case. Frequently, scratching and chipping of the element resulted.

3. Incomplete blackening of base and three sides of glass element. This type of defect changes the light absorption and hence the fluorescence reading.

4. Irregularities in the glass element. Some were smooth-surfaced, some polished, some rippled, and others had a ground glass surface.

5. Incorrect initial readings. During production, all DT-60's received a "pre-dose" which was sufficient to raise the fluorescence to an arbitrary value between 0 and 10 r on the reader. Several dosimeters were found to be unusable because their initial readings were considerably below zero.

It is apparent, therefore, that stricter quality control must be maintained during production in order to increase the reliability and decrease the number of defective dosimeters manufactured.

3.1.1 Energy Dependence

The effect of X or gamma irradiation of silver-activated phosphate glass is known to vary inversely with the photon energy below 200 kev. Schulman et al.² described the response at 70 kev as being 18 times greater than at 13 Mev. In the DT-60, this energy dependence has been reduced by sandwiching the glass element between two lead filters of ~30 mil thickness. To prevent a continuing downward response below 180 kev, a small hole was centrally located in each filter. This resulted in a fairly linear response down to at least 125 kvp filtered X rays (approximately 80 kev), provided the plane of the DT-60 and its shielded surfaces were perpendicular to the plane of an anisotropic radiation. If the plane of the DT-60

was parallel (the unshielded sides perpendicular) to unidirectional radiation below 200 kev, an exaggerated response was found. Two hundred and fifty kvp X rays filtered to ~ 180 kev average energy resulted in a three-fold increase over actual dose when the plane of the DT-60 was placed parallel to the plane of the field. At 120 kvp (~ 80 kev average energy), the exaggeration was fourfold. A similar but not so marked effect would be predicted in an isotropic field, regardless of orientation of the DT-60 (see Fig. 4).

3.1.2 Response Lag Time

A sufficient number of dosimeters were examined to determine that several hours must elapse between exposure and reading before identically exposed dosimeters will either reach agreement or approximate the actual dose received. By 2 hours after exposure, all dosimeters will have reached fair agreement and will approximate 75 per cent or more of the total dose received. By 4 hours, the variations will be sufficiently small as to be obscured within the limits of reliability of the DT-60. An article in the literature by Schulman et al.² suggests that the "build-up" or lag time varies inversely with silver content of the glass. The reason for the lag or build-up time does not appear to be well understood.

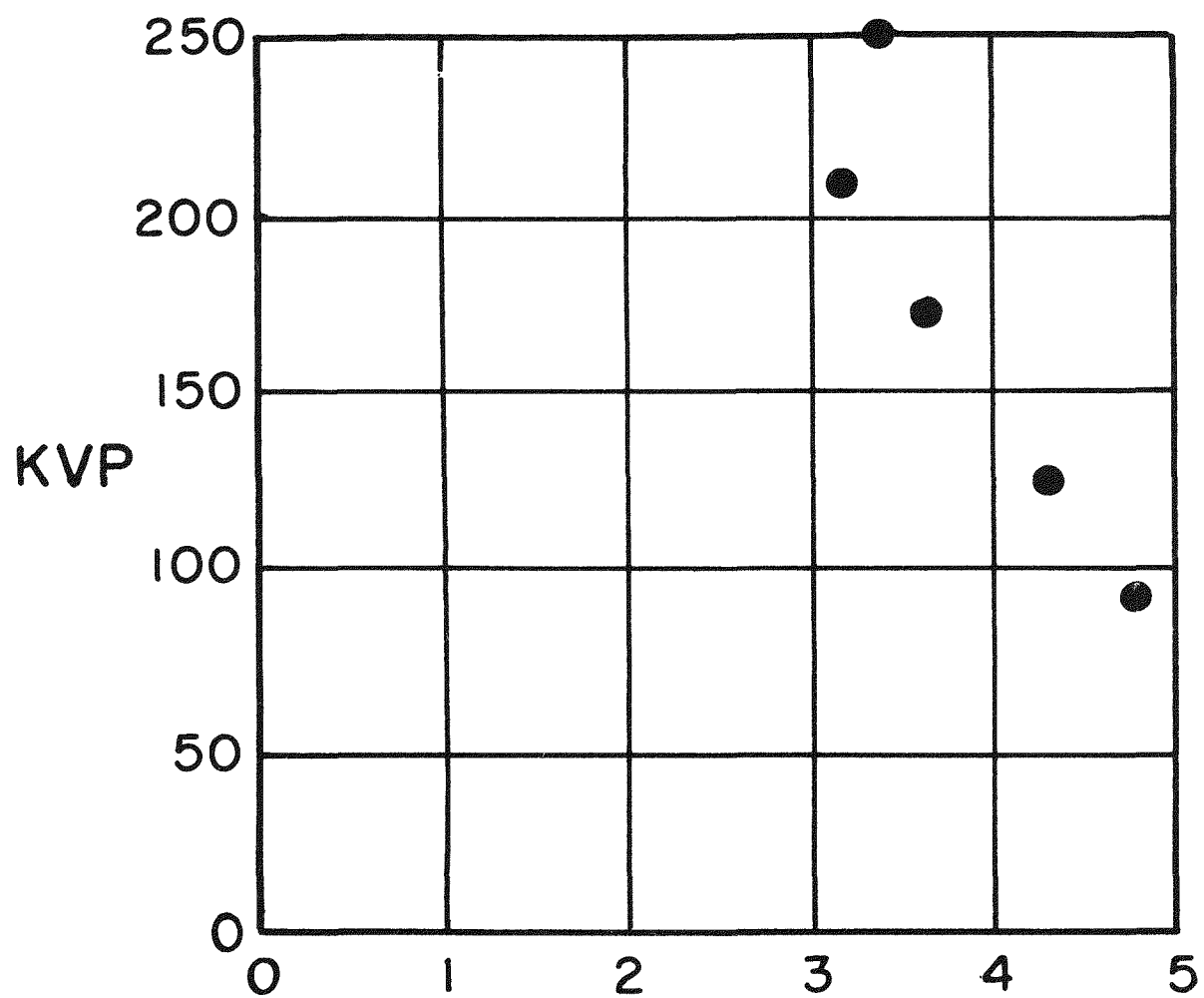


Fig. 4. Directional dependence curve.

3.1.3 Accuracy

The manufacturers claim that the DT-60 is accurate to within 20 per cent with a minimum detectable dose of 10 r. Graduated exposures on the Health Research Laboratory's (HRL) 250 kvp X ray machine indicated that any single reading below 20 r was apt to be quite unreliable, due in part to the DT-60 itself and in part to the inherent variations in the two CP-95A readers which were examined. From 25 to 75 r, the deviation appeared to be 20 per cent; as exposures from 100 to 600 r were made, the deviation was reduced from 15 to 10 per cent, respectively.*

3.1.4 Reproducibility

The ability of a DT-60 to give repeated readings following identical exposures was within the limits of accuracy given in Sec. 3.1.3, as was the agreement between a group of dosimeters. However, within a group of 160 dosimeters examined, over 8 per cent were removed as defective because their readings were only 40 to 60 per cent accurate. Although the number of dosimeters tested was admittedly small, this extreme inaccuracy, coupled with the

*Accuracy was not checked at other energies, and some 8 per cent faulty dosimeters were excluded from these values.

fact that the inaccuracy of the remainder varied from 5 to 20 per cent, does not suggest the normal distribution one might expect from a random sampling of quality controlled production.

3.1.5 Dose Rate Dependence

No detectable dose rate dependence could be demonstrated at rates from 10 to $\sim 10^6$ r per hour (Cs¹³⁷, bomb test exposure).

3.1.6 Temperature Effect

Temperature effects at three different times have been reported in the literature.² These are:

1. The temperature at time of exposure.
2. The temperature at time of reading.
3. The temperature between times 1 and 2 above.

In all three cases, the readings vary with the temperature. Since the DT-60 is to be worn on the body until read and since reading will presumably be done at room temperature, it was believed that the temperature effect would not result in any appreciable error within the intended use of the device and it was, therefore, not examined.

3.1.7 Aging Effects

Over a 9 month period of examination of the DT-60 in the HRL, no change of fluorescence reading as a function of time was observed.

3.1.8 Deterioration

A fungus-like growth or cloudiness has been reported to develop on the surface of the glass element, thereby reducing or increasing the reading (depending upon the fluorescent nature of the contaminant). Such was not observed during the HRL examination period. All "open" operations were conducted while wearing rubber or cotton gloves. Whether temperature or humidity plays a role in this reported surface contamination is not known, but the gasket material used in sealing the locket, as well as the adhesive used to hold the locket components in place, have been reported to have certain fluorescent characteristics which, upon deterioration and flaking off, could be responsible for some of the observed difficulties.

The Air Force Special Weapons Center (AFSWC) at Kirtland Air Force Base, New Mexico, has designed a modified CP-95 reader which, through a mirror lens and shutter system, sights the photomultiplier tube principally upon the center of the glass element and thus reduces any possible

fluorescence component contributed by surface contamination.³

3.2 X and Gamma Ray Responses

Assuming similar orientation of the dosimeters placed at right angles to the plane of radiation from a 250 kvp X ray source, a 660 kev Cs¹³⁷ gamma source, a 1.3 Mev Co⁶⁰ gamma source, and the contaminant gamma spectrum in the thermal columns of the Los Alamos Homogeneous Reactor, any energy dependence is within the limits of accuracy of the DT-60. Although the radiation from all but the reactor was essentially unidirectional and thus shielded by the DT-60 lead filters, the fairly isotropic field within the graphite of the thermal column should have demonstrated some energy dependence characteristic of the unshielded sides of the glass element. The fact that this was not demonstrable was due to the characteristic contaminant gamma in the column which has a narrow spectrum, peaking at 4 Mev with a maximum energy at 4.9 Mev. During the Humboldt shot at Nevada, DT-60's surrounded by 1/2 in. lithium were expected to give a gamma-only reading. The readings obtained from four positions between 240 and 370 yards from Ground Zero were within a few per cent of the gamma dose as determined by gamma dosimeters of Ott⁴ using Victoreen correction values.

3.3 Thermal Neutron Response

Using 10 layers of 1/8 in. lithium to shield against thermal neutrons in the north thermal column of the reactor, the DT-60 and Victoreen readings were found to be comparable. By progressively removing one 1/8 in. thickness of lithium at a time, an extrapolation of the Victoreen gamma dose at zero thickness of lithium was made, and the gamma dose thus determined was subtracted from the reading of the DT-60 placed at the same position and unshielded by lithium. The DT-60 reading minus the determined gamma dose was five times greater than the actual single collision thermal neutron dose as determined by gold foil activation measurements. Thus, for every rep of thermal neutrons received, the DT-60 indicated 5 r. The reason for this fivefold exaggeration of the thermal neutron dose may be due to the high cross section of silver, which, through subsequent decay and gamma emission, becomes an internal source within the AgPO_3 glass element.

Since the decay half-lives involved are 22 seconds for the $({}_{47}\text{Ag}^{109} + n \longrightarrow {}_{47}\text{Ag}^{110*} \longrightarrow {}_{48}\text{Cd}^{110} + \beta, \gamma)$ and 2.3 minutes for the $({}_{47}\text{Ag}^{107} + n \longrightarrow {}_{47}\text{Ag}^{108*} \longrightarrow {}_{48}\text{Cd}^{108} + \beta, \gamma)$, it would appear that essentially complete decay will occur during the normal 2 to 4 hour dosimeter lag time (see Sec. 3.1.2).

3.4 Fast Neutron Response

At distances ~ 100 cm from Godiva II (a bare critical assembly of ~ 60 kg enriched U^{235}), the fast neutron-gamma ratio is $\sim 10:1$. Five hundred rep of fast neutrons (50 rep gamma), delivered in bursts or at ~ 100 r per minute, failed to effect any measurable response in the DT-60 after the 10 per cent gamma contribution was subtracted from the reading. Assuming a 50 r gamma reading to be ± 20 per cent, it would be possible that 40 r was gamma and 10 r due to fast neutrons. This would set the upper threshold for fast neutron response at 10:500 or ≤ 2 per cent.

3.5 Field Response

In order to examine better the limitations, capabilities, and potentialities of the $AgPO_3$ glass system as a disaster dosimeter for mixed radiation, arrays of DT-60's in different configurations (see Appendix for examples) were set up from 240 to 530 yards from Ground Zero on shot Humboldt of Hard-tack Phase II, which had a neutron to gamma ratio of about 2:1 and a fast to thermal neutron ratio of 3:1 between the 240 to 530 yard lines. Table I lists the assemblies, station locations, and averaged dosimeter readings for each array; comparative dosimetry data are given in Table II. Results were as follows:

TABLE I. Averaged Dosimeter Readings for Humboldt Shot Arrays, R

Assembly	Distance, yds						
	240	265	305	330	370	450	530
DT-60	362	274	195		102	55	31
DT-60 paraffin			232		119		
DT-60 lithium	305	246	156				
DT-60 lithium-paraffin			159		83		
DT-60 cadmium			314		169	84.5	
DT-60 cadmium-paraffin			438	350	224	117	58
DT-60 paraffin (front)			232				
DT-60 paraffin (back)			199				
DT-60 pig (front)		396	288		147		39
DT-60 pig (back)		322	215		108		29

TABLE II. Comparative Dosimetry Data (Humboldt data normalized to least squares fit), R

Assembly	Distance, yds					
	240	265	305	370	450	530
DT-60	357	274	184	104	56	32
DT-60 paraffin	485	360	228	117	56.5	28
DT-60 lithium	310	236	156	86.5	45.5	25
DT-60 lithium-paraffin	314	236	154	83.5	42.3	23
DT-60 cadmium-paraffin	938	694	445	235	113	59
DT-60 cadmium-paraffin	0.865	0.848	0.800	---	---	--
<u>Total dose</u>						
DT-60 - DT-60 lithium	47	38	28	17	10	7
DT-60 - DT-60 lithium	6.15	6.66	7.65	---	---	--
<u>Thermal neutron</u>						
Doses						
Gamma	313	241	163	94	52	30
Fast neutron	765	572	389	204	105	59
Thermal neutron	7.65	5.7	3.66	---	---	--
<u>Total dose</u>	1086	819	556	298	157	89

1. DT-60 readings were approximately one-third the total dose received. Performance was examined in mixed radiation between isodose lines of physiological significance (100 to 1000 r).

2. DT-60 and paraffin were examined to determine the DT-60's performance as a mixed radiation disaster dosimeter. The wearer was simulated by a paraffin block 8 x 8 x 4 in., which is equivalent to the tissue thickness of an individual's chest wall. It was estimated that if a person had worn the DT-60 on shot Humboldt, it would have read about 43 per cent of the total dose received.

3. DT-60 in lithium was set up to determine the DT-60's response to the gamma component of a nuclear detonation. The agreement with trichloroethylene chemical dosimeters corrected to Victoreen values⁵ was within 3 per cent.

4. DT-60 in lithium backed by paraffin was used to estimate the effect of a wearer upon the gamma-only part of a paired DT-60 dosimeter. No significant difference was seen when compared with the data for lithium alone.

5. DT-60 in cadmium was measured in an attempt to exaggerate the thermal neutron response because the DT-60 does not respond significantly to fast neutrons. Within isodose lines of physiological interest, the fast neutron to thermal neutron ratio for 15 shots representative of

yields from tons to megatons was roughly from 2:1 to 3:1 and averaging 2.5:1. For shot Humboldt it was 3:1, due probably to the essentially unshielded aspect of the weapon which faced the dosimeters. On a first collision basis, the energy given up by a fast neutron is roughly 60 times that of a thermal neutron. Thus, a 2.5:1 ratio of F_{N_f} to $F_{N_{th}}$ will equal a 150:1 ratio of dose. If we can assume the fast to thermal neutron ratio to be roughly 2.5:1 between the 100 to 1000 r isodose lines for all weapons (as from test data review), it appears that by using cadmium to exaggerate further the thermal neutron response we may more closely approximate the total neutron dose. The DT-60 in cadmium approximated 60 per cent of the total dose.

6. DT-60 in cadmium backed by paraffin was intended to simulate the dose recorded by the DT-60 cadmium system when worn by field personnel. It was determined that this system will approximate 80 per cent of the total dose received between 100 to 1000 r isodose lines (Fig. 5).

7 and 8. DT-60 backed and shielded by paraffin was used to determine the directional effect of orientation of the wearer to Ground Zero. It was observed that with paraffin between the wearer and Ground Zero, approximately 15 per cent reduction in dose was recorded by the DT-60. This is believed to be the result of gamma attenuation.

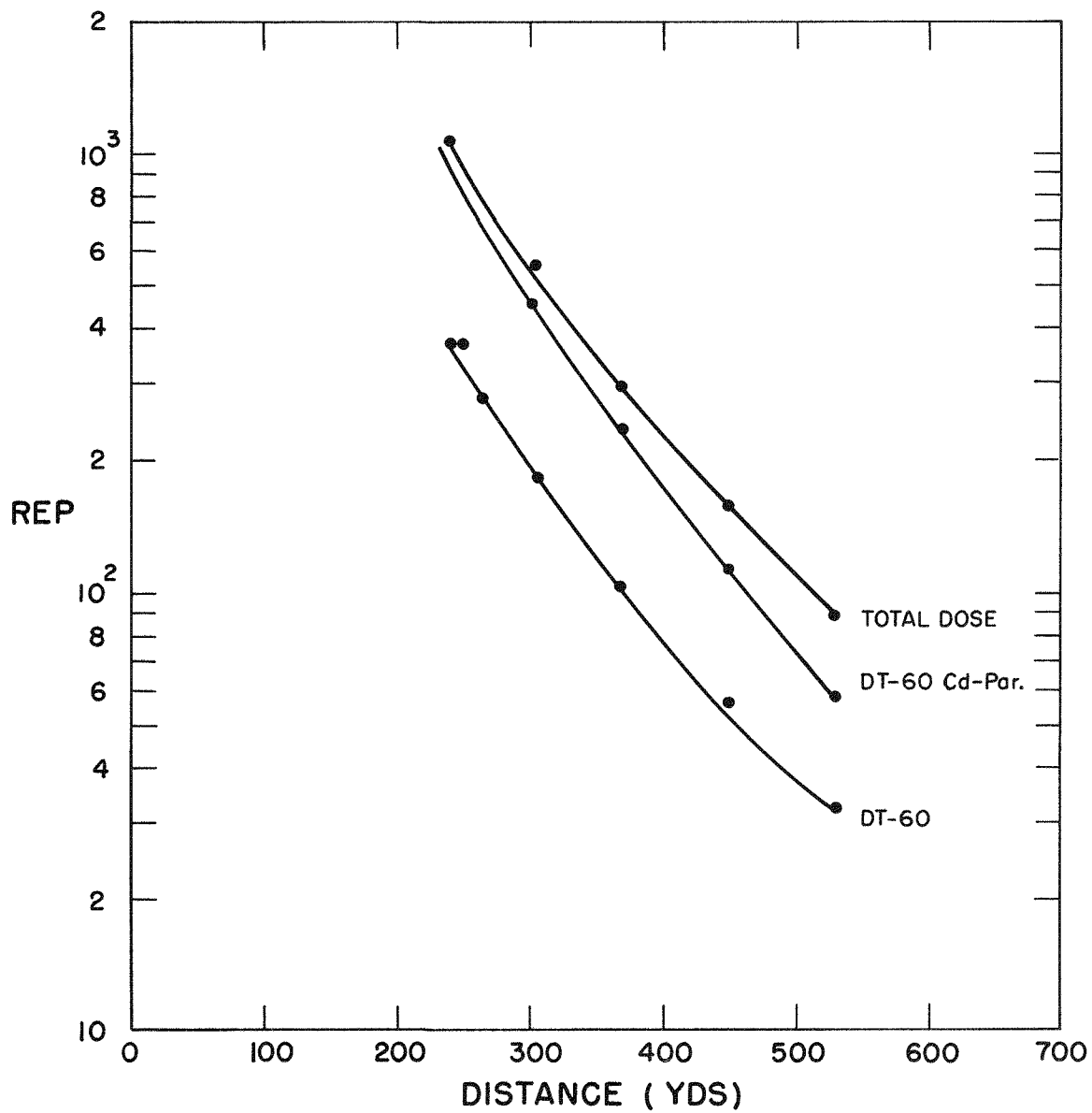


Fig. 5. DT-60 and DT-60 cadmium-paraffin readings versus actual dose curves.

9 and 10. DT-60 backed and shielded by implantation under the skin of a pig was used to simulate more closely the wearer and to obtain a pig to paraffin ratio. The readings will not stand the test of mathematical significance because of the small number of subjects (4 pigs), spread of data, and leaking gasket material. An increase of roughly 15 per cent in the recorded dose was seen when compared with the paraffin data. This increase is probably due in part to increased thermalization of fast neutrons due to the greater mass of the pig and in part to temperature differential between the pig and ambient air. Whatever portion is the result of an increase in thermal neutrons would further reduce the disparity between the cadmium-paraffin dose and the actual dose (a difference of about 20 per cent).

It should be pointed out that neither fast neutron nor thermal neutron measurements were made beyond 300 yards and that within 200 yards the data began to flatten out. Thus the least squares fast neutron data in Table II cannot reasonably be extended beyond 400 yards and the thermal neutron data beyond 300 yards. A least squares analysis technique was used to extrapolate neutron dose and interpolate DT-60 data so that a comparison could be made at

common distances. The use of this technique is the probable reason for the decreasing ratio of the DT-60 plus cadmium and paraffin to total dose with distance and the increasing ratio of the DT-60 minus DT-60 with lithium to thermal neutrons with distance.

CHAPTER 4

DISCUSSION

The DT-60 silver-activated phosphate glass dosimeter has been evaluated in the following respects:

1. In terms of its prescribed use, which is to say, as an integrating lifetime or disaster type gamma and X ray dosimeter for military personnel.

2. In terms of its actual use, that is, as a dosimeter for personnel exposed not only to X and gamma radiation but to mixed radiations from many sources.

3. In terms of possible improvements or modifications to the present system which will (a) increase its general usefulness, (b) enhance its utility for specific dosimetric purposes, and (c) make use as far as possible of the existing system in which an investment of approximately 3 million dollars has already been made by the military.

The DT-60 is in use today by all Navy and Air Force military personnel. Discounting a nuclear war, its primary

utility is as an accumulating or disaster dosimeter for those military personnel associated with weapon test programs, power and propulsion reactors, X ray equipment, gamma sources, and research activities that additionally involve working with isotopes, critical assemblies, research reactors, etc. Such activities involve exposure to mixed radiations, and in many cases the critical or limiting component is the neutron flux rather than the gamma radiation. In such situations, the DT-60 may prove to be worse than useless in that it will give misleading information. Alternatively, in terms of a massive nuclear accident or nuclear war involving military personnel not normally associated with radiation hazards, the requirements for a mixed radiation disaster dosimeter are not met by the present unmodified DT-60. In shot Humboldt, the DT-60's worn by pigs indicated an exposure roughly one-half that actually received.

4.1 X and Gamma Responses

The DT-60 was designed for use as an X and gamma dosimeter. Within these limitations it has several outstanding faults which, however, appear to be easily amendable.

It is directionally dependent to anisotropic radiation

at energies below 200 kev. Unfortunately, anisotropy and energies below 200 kev are fairly characteristic of most X ray equipment and thus are features which work particularly against the rather limited use of the existing DT-60. Instead of the lead filter sandwich, the glass element should be completely encased by the filter material.

Dosimeters examined by HRL exhibited evidence of loose design specifications and rather poor quality control during manufacture (see Sec. 3.1). Eight per cent of the 160 examined gave such unreliable readings as to require rejection. Encasing the glass element in a tough plastic film with good optical qualities, a better seal, and an airtight gasket would reduce the number of defective dosimeters considerably, and closer control over the composition and molding of the glass element would further improve them.

Provision should be made for recording the latest reading inside the case. In the event of a radiation accident, it is quite possible that the medical records containing the previous readings of the individuals involved will not be available immediately.

4.2 Mixed Radiation Response

4.2.1 Specific Spectra

By use of such techniques as cadmium covers and lithium

shields, it is possible to produce DT-60's modified for a specific neutron to gamma or fast neutron to thermal neutron ratio, as was attempted on Humboldt shot (see Sec. 3.5). Since the total accumulated dose on an unmodified DT-60 consists of the gamma dose plus an exaggerated thermal neutron response plus an insignificant or zero response to fast neutrons, we can say that the DT-60 reading equals $D_\gamma + kD_{N_{th}}$. The symbol k , in terms of the thermal column results, was a value between 5 and 6. For the Humboldt test, a k value of ~ 6.5 was obtained. If we desire a DT-60 to read a $D_\gamma + kD_{N_{th}}$ which is equal to the actual $D_\gamma + D_{N_f} + D_{N_{th}}$, then k must equal $D_{N_f}/D_{N_{th}} + 1$. A review of 15-odd shots with yields from tons to megatons revealed that between isodose lines of physiological significance (100 to 1000 r) the ratio of fluxes of fast to thermal neutrons averages about 2.5. As pointed out earlier, if on a first collision basis a fast neutron gives up about 60 times the energy of a thermal neutron, then a desirable value for k would be ~ 150 , or $2.5 \times 60 + 1$. In the rough trial and error method used in the DT-60 cadmium-paraffin assemblies for Humboldt, k may be determined as follows (values from data at 305 yards, Table II):

$$\text{DT-60} + \text{cadmium-paraffin} = D_{\gamma} + kD_{N_{th}}$$

where

$$\text{DT-60} + \text{cadmium-paraffin} = 445$$

$$D_{\gamma} = 163$$

$$D_{N_{th}} = 3.66$$

$$k = \text{unknown}$$

$$445 = 163 + k3.66$$

$$445 - 163 = 3.66k$$

$$3.66k = 282$$

$$k = 77$$

This is roughly one-half the 150 desired. Thus by adding cadmium to the DT-60 system, we have increased k from ~ 6.5 to 77. If we can assume, as well we must for this technique to be successful, that between the isodose lines of physiological significance for all yields the ratio of neutron fluxes is ~ 2.5 , then any technique to increase k further toward 150 will more closely approximate the actual dose received. Investigations of optimum thickness of cadmium, optimum surface area to volume relations in the glass element, as well as the possibility of adding such material as cadmium to the glass mix, appear to offer a reasonable approach.

Although the utility of this dosimeter for other types of mixed or neutron radiation is generally destroyed by this type of modification, the enhancement of its specific utility may overshadow this consideration in particular situations.⁶ With the development of specialized types and special purpose reactors, it is likely (as with the Army power and Navy propulsion reactors) that families of reactors with common spectra (fast neutron to thermal neutron and neutron to gamma ratios) will develop. With the development of such families of reactors, a concomitant program to develop a special purpose dosimeter limited in use to the particular reactor family would be of particular value to personnel associated exclusively with this type of radiation equipment.

4.2.2 Nonspecific Spectra

In considering a massive nuclear accident or nuclear war, the requirements for a general purpose mixed radiation dosimeter for all military personnel are not met by the present DT-60. In such situations, a paired system of DT-60's might prove to be the best technique for a minimum of investment. By shielding one of the paired glass elements from thermal neutrons and by correcting the other to read gamma plus thermal neutrons on a roentgen for roentgen basis, one would always have a gamma-only reading,

a thermal-neutron-plus-gamma reading, a thermal-neutron-only reading, and a gamma to thermal neutron ratio. With this information, plus a rough estimate of either neutron to gamma or fast neutron to thermal neutron ratios (which is generally available), one might for purposes of medical treatment or military decision quite closely approximate the total dose received (Fig. 6).

The gamma-only portion of such a paired system would probably involve a thermal neutron absorber such as lithium. To obtain adequate shielding with normal lithium, thicknesses of $\sim 1/2$ in. appear to be required. This would result in an over-all increase in the DT-60 dimensions of 1 in. The alternatives are several:

1. The glass element could be reduced in size.
2. The silver content of the glass element could be reduced.
3. Lithium-6, which has 10 to 15 times the N_{th} cross section of natural lithium (Li^{6+7}), could be used, or a natural lithium compound in which the lithium per unit mass is greater than that in natural lithium could be used.

The gamma plus thermal neutron portion of such a paired system (where the N_{th} response was corrected to $k = 1$) might be achieved by lithium-plating of the glass or the locket, by reducing the silver content of the glass, or by

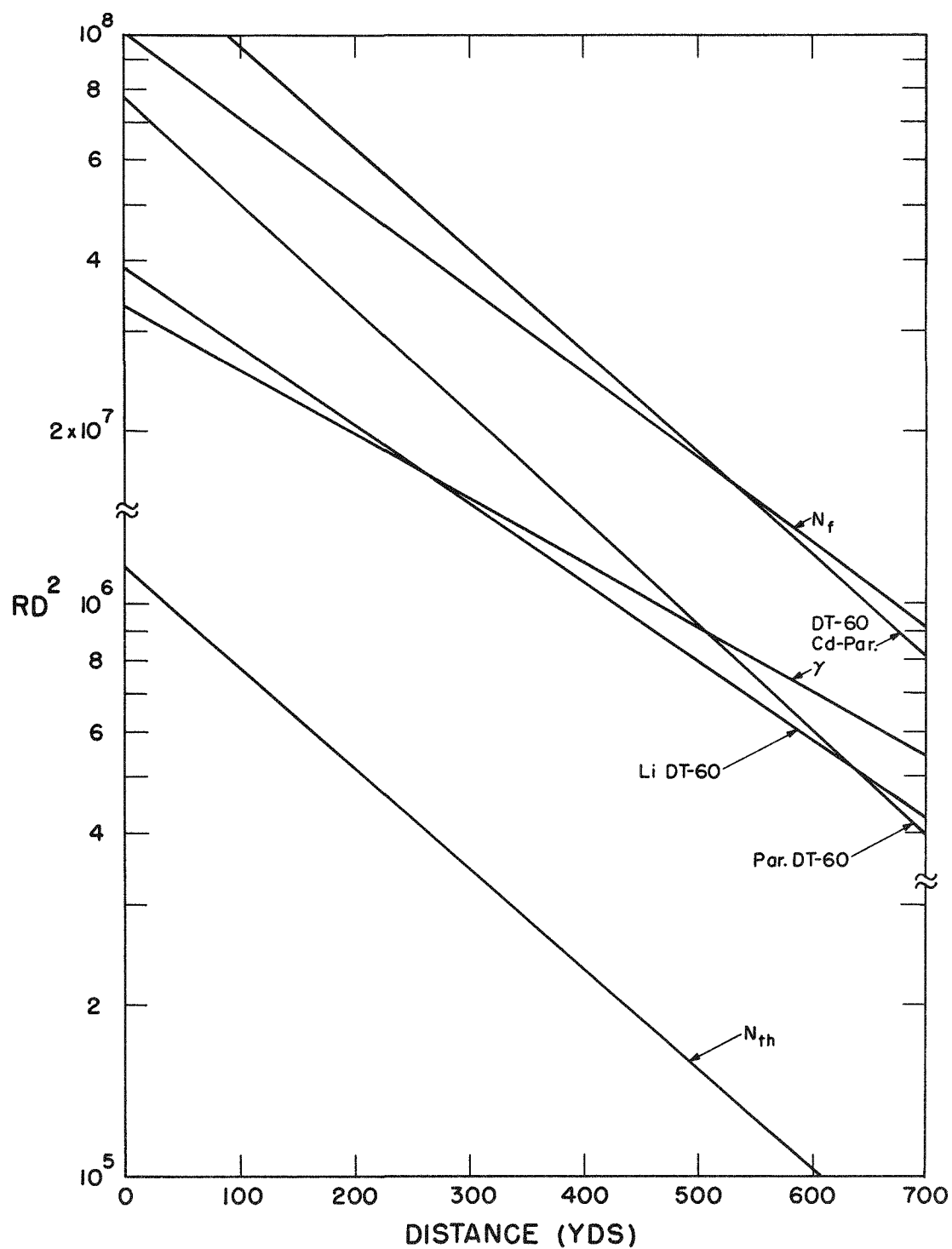


Fig. 6. RD^2 plot versus D for N_f , N_{th} , γ , DT-60, DT-60 lithium, and DT-60 cadmium-paraffin.

the use of B^{10} to convert neutrons to gammas, and thus eliminate the inherent kN_{th} exaggeration.

The danger here is that, if one uses an assumed ratio of fast to thermal neutrons to arrive at a fast neutron estimate from thermal neutron measurements and if the dose contribution from the fast component is many times that of the thermal component, small variations in the DT-60 thermal readings will result in large errors in the fast neutron estimates. In any mixed field measurements, it is more desirable to measure gamma, fast neutrons, and thermal neutrons separately than to have a single composite reading of total dose, a portion of which need be corrected with one RBE value and another portion by another RBE value.

Thus a more desirable system would be to use a lithium-clad DT-60 for gamma dose, a normal DT-60 for gamma plus thermal values (which by subtraction will give the thermal dose), and a supplementary method to accomplish fast neutron measurements (such as a cadmium-clad gold foil whose induced activity can be measured by solid scintillation-counting equipment). A modification of the above would be to use a single lithium-clad DT-60 for gamma dose and paired gold foils, one of which is cadmium-clad, to obtain fast and thermal neutron values.

An interesting technique, which arose as a consequence

of the Kelley incident, is that of measuring the gamma activity of Na^{24} produced in the body by thermalized neutrons.

Preliminary data suggest that as little as 10 rads of fast neutrons in a whole body dose will result in sufficient Na^{24} activity as can be read by a 2 in. sodium iodide crystal on a 2 in. diameter photomultiplier tube as long as 15 hours post exposure. Since the effective half-life of Na^{24} in man is approximately 15 hours, it would follow that ~ 30 rads of fast neutrons could be read out to a period of 2 days.

Measurements can be made by holding the photomultiplier scintillator assembly against the body at a point overlying a vascular area, such as that portion of the back overlying the renal arteries and veins or that portion of the lower anterior chest wall overlying the hepatic area. Such a device, with the necessary electronics and a circuitry designed to allow the activity to be corrected to time zero, can be made for field use, and either this system or the gold foil system will closely approximate the CP-95A reader in size, shape, and cost.

The result would be a versatile field dosimetry system for any mixed radiation field.

CHAPTER 5

SUMMARY AND RECOMMENDATIONS

As a lifetime integrating or disaster type X or gamma-only type dosimeter, the inadequacies of the present DT-60 can be easily overcome by (1) obtaining better quality control of manufacturing; (2) encasing the glass element completely in a protective, optically clear seal; and (3) extending the present partial lead shielding to shield totally the glass element from radiation in its energy dependent region.

As a lifetime integrating or disaster type mixed or neutron type dosimeter, the inadequacies of the present DT-60 preclude its safe use. Several methods are suggested for modifying the present system to give it utility either as a specific purpose dosimeter or as a mixed radiation disaster dosimeter. To accomplish the former generally reduces its value as the latter and vice versa, unless the different components (gamma, thermal, and fast neutrons) are

measured separately. Thus the merits of each must be considered in terms of the intended use, and a compromise is not likely to produce a device of much more value than the present DT-60.

It is urged that a policy be adopted which will lead to the early replacement of the present DT-60 by one of the systems described under Chapter 4 and to a modest research and development effort to design and test special purpose dosimeters for the limited number of military personnel normally associated with particular types of radiations and related hazards.

It is felt that the mixed radiation dosimetry systems described, as well as the special purpose dosimeter, could be developed to supplement rather than replace the present DT-60 system. A recommended approach is as follows:

1. Immediate discontinuance of all DT-60 or CP-95 purchases, either as additional stock or as replacements.
2. Immediate contract negotiations to establish a Modification, Study, Design, and Test agency which will lead to contractual arrangements for production of a mixed radiation dosimetry system utilizing (where economy and expediency dictate) the features of the present DT-60 system.
3. A modest research and development effort to design

and examine special purpose DT-60's for use by a limited number of personnel associated with particular types of radiation and related hazards.

4. Interim consideration of a modified DT-60 to include, but not necessarily to be limited to, the following changes: (a) full surface shielding of glass element; (b) rigid quality control of glass composition, finishing, and assembly; (c) reduction of thermal neutron response to approximately a 1:1 ratio; and (d) alternative to c, elimination of thermal neutron response.

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APPENDIX

DISASSEMBLED SAMPLES USED ON HUMBOLDT SHOT
AND REPRESENTATIVE EXPOSURE ARRAY



Fig. A.1. Disassembled DT-60 lithium test sample.

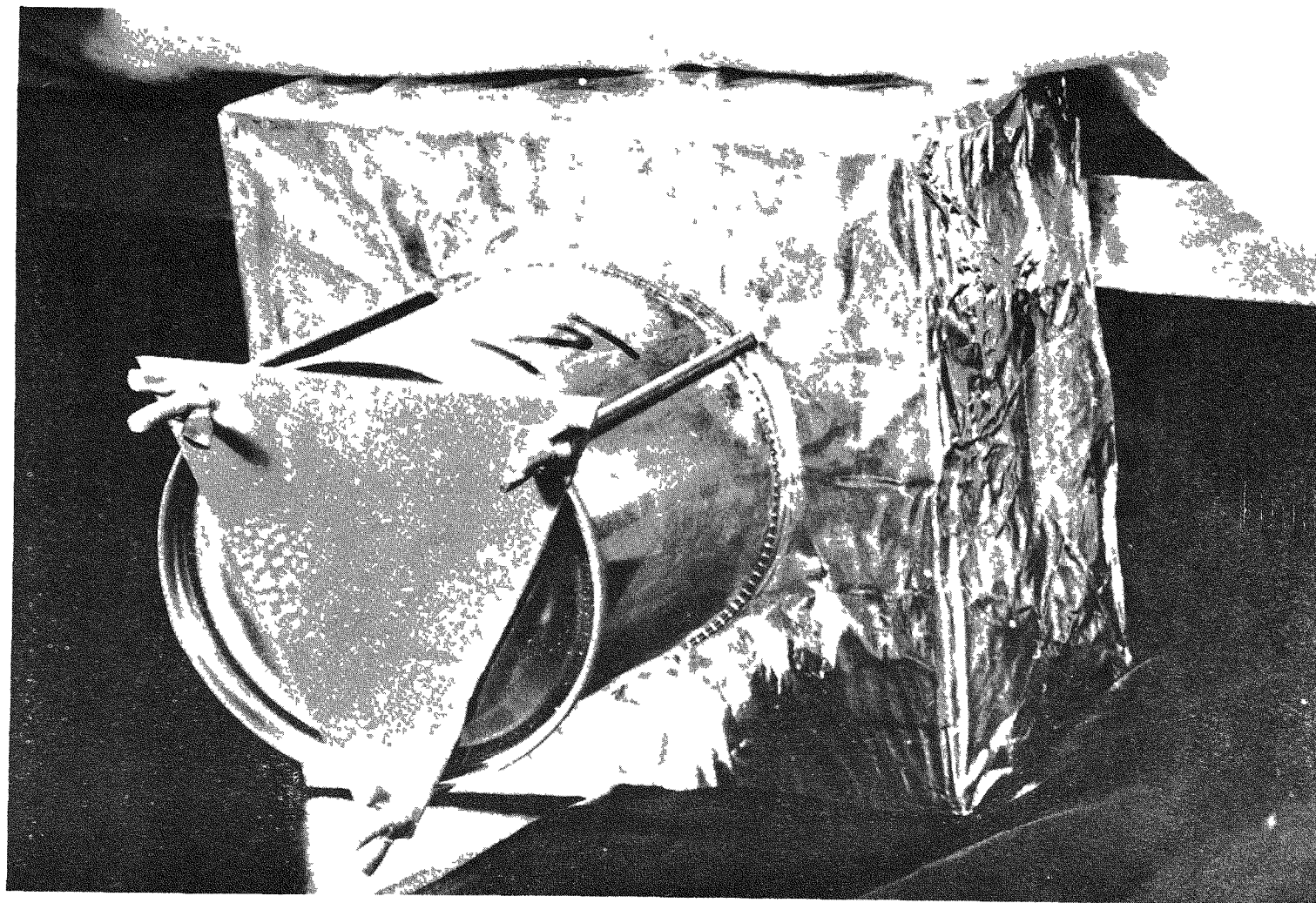
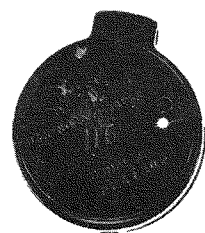
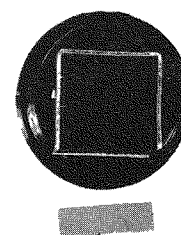
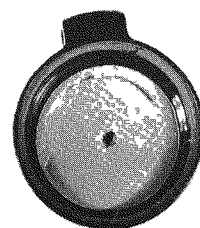


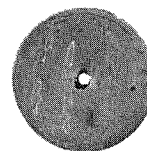
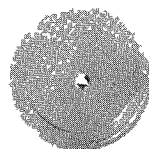
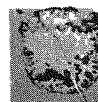
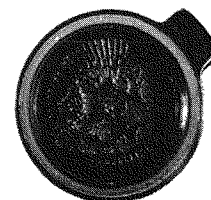
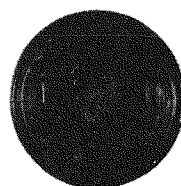
Fig. A.2. DT-60 lithium-paraffin test sample.



ASSEMBLED



DISASSEMBLED FOR READING



DISASSEMBLY OF COMPONENTS

Fig. A.3. DT-60 cadmium assembled and disassembled..

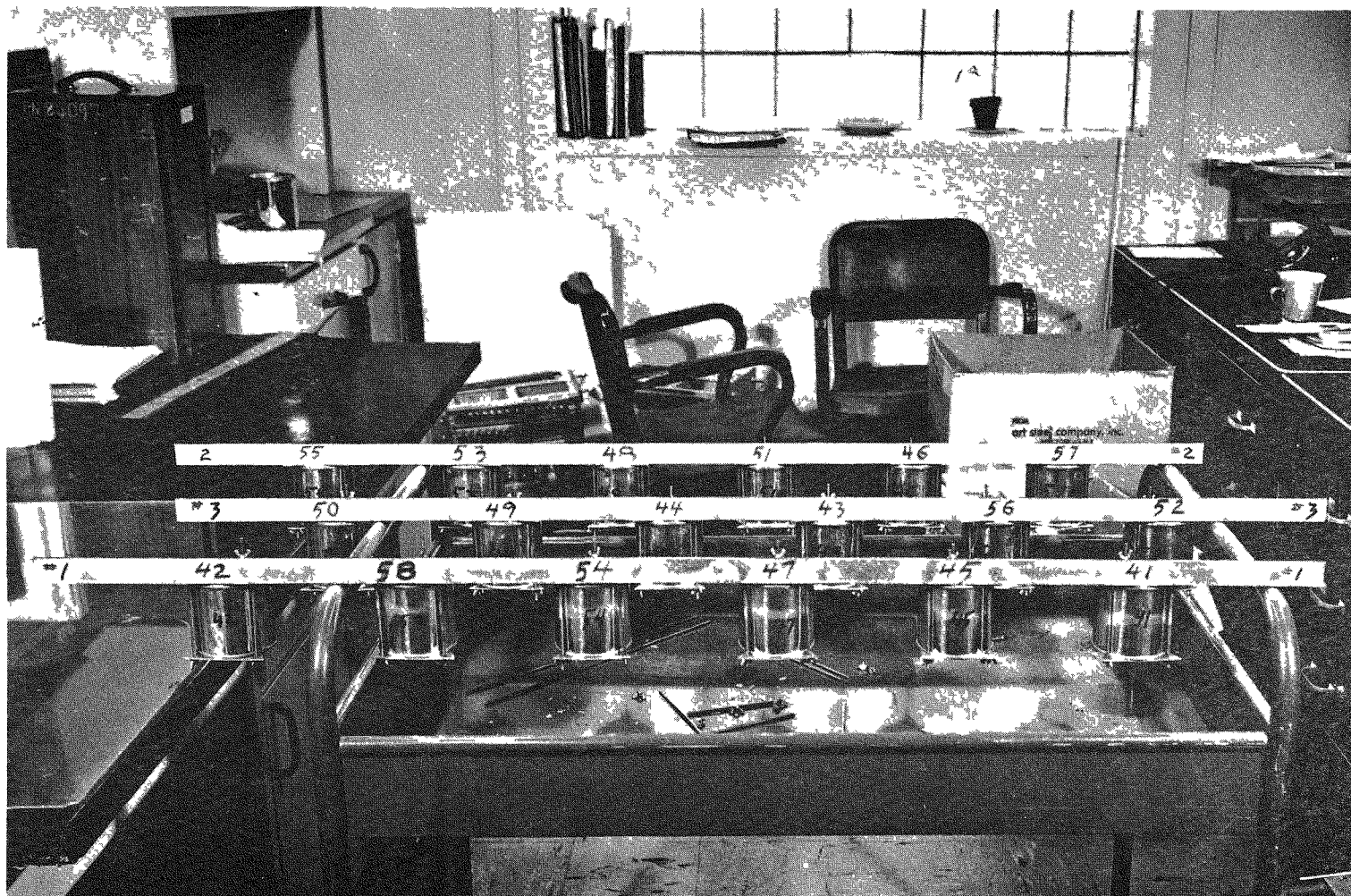


Fig. A.4. DT-60 lithium array (representative of all arrays used on Humboldt test).